APPARATUS FOR DETERMINING THE LOCATION OF A POINTER WITHIN A REGION OF INTEREST

Field of the Invention

[001] The present invention relates generally to input systems and in particular to an apparatus for determining the location of a pointer within a region of interest.

Background of the Invention

[002] Touch systems are well known in the art and typically include a touch screen having a touch surface on which contacts are made using a pointer in order to generate user input. Pointer contacts with the touch surface are detected and are used to generate corresponding output depending on areas of the contact surface where the contacts are made. There are basically two general types of touch systems available and they can be broadly classified as "active" touch systems and "passive" touch systems.

[003] Active touch systems allow a user to generate user input by contacting the touch surface with a special pointer that usually requires some form of on-board power source, typically batteries. The special pointer emits signals such as infrared light, visible light, ultrasonic frequencies, electromagnetic frequencies, etc. that activate the touch surface.

[004] Passive touch systems allow a user to generate user input by contacting the touch surface with a passive pointer and do not require the use of a special pointer in order to activate the touch surface. A passive pointer can be a finger, a cylinder of some material, or any suitable object that can be used to contact some predetermined area of interest on the touch surface.

[005] Passive touch systems provide advantages over active touch systems in that any suitable pointing device, including a user's finger, can be used as a pointer to contact the touch surface. As a result, user input can easily be generated. Also, since special active pointers are not necessary in passive touch

systems, battery power levels and/or pointer damage, theft, or misplacement are of no concern to users.

[006] International PCT Application No. PCT/CA01/00980 filed on July 5, 2001 and published under No. WO 02/03316 on January 10, 2002, assigned to SMART Technologies Inc., assignee of the present invention, discloses a camera-based touch system comprising a touch screen that includes a passive touch surface on which a computer-generated image is presented. A rectangular bezel or frame surrounds the touch surface and supports digital cameras at its corners. The digital cameras have overlapping fields of view that encompass and look across the touch surface. The digital cameras acquire images looking across the touch surface from different locations and generate image data. Image data acquired by the digital cameras is processed by digital signal processors to determine if a pointer exists in the captured image data. When it is determined that a pointer exists in the captured image data, the digital signal processors convey pointer characteristic data to a master controller, which in turn processes the pointer characteristic data to determine the location of the pointer relative to the touch surface using triangulation. The pointer location data is conveyed to a computer executing one or more application programs. The computer uses the pointer location data to update the computer-generated image that is presented on the touch surface. Pointer contacts on the touch surface can therefore be recorded as writing or drawing or used to control execution of applications programs executed by the computer.

[007] Although the above touch system works extremely well, the use of four digital cameras and associated digital signal processors to process image data captured by the digital cameras makes the touch system hardware intensive and therefore, increases the costs of manufacture. This of course translates into higher costs to consumers. In some environments where expense is of a primary concern, less expensive touch systems are desired.

[008] A camera-based touch system having reduced hardware has been considered. For example, U.S. Patent No. 5,484,966 to Segen discloses an apparatus for determining the location of an object within a generally rectangular active area. The apparatus includes a pair of mirrors extending along different sides of the active area and oriented so that the planes of the mirrors are substantially perpendicular to the plane of the active area. The mirrors are arranged at a 90 degree angle with respect to one another and intersect at a corner of the active area that is diametrically opposite a detecting device. The detecting device includes a mirror and a CCD sensor and looks along the plane of the active area. A processor communicates with the detecting device and receives image data from the CCD sensor.

[009] When a stylus is placed in the active area, the detecting device sees the stylus directly as well as images of the stylus reflected by the mirrors. Images including the stylus and stylus reflections are captured by the detecting device and the captured images are processed by the processor to detect the stylus and stylus reflections in the captured images. With the stylus and stylus reflections determined, the location of the stylus within the active area is calculated using triangulation.

[010] Although this apparatus reduces hardware requirements since only one optical sensing device and processor are used, problems exist in that at certain locations within the active area, namely along the side edges and the corner diametrically opposite the detecting device, resolution is reduced. As will be appreciated, a touch system that takes advantage of reduced hardware requirements yet maintains high resolution is desired.

[011] It is therefore an object of the present invention to provide a novel apparatus for determining the location of a pointer within a region of interest.

Summary of the Inv ntion

[012] According to one aspect of the present invention there is provided an apparatus for detecting a pointer within a region of interest comprising:

a first reflective element extending along a first side of said region of interest and reflecting light towards said region of interest;

a second reflective element extending along a second side of said region of interest and reflecting light towards said region of interest, said second side being joined to said first side to define a first corner;

a non-reflective region generally in the plane of at least one of said first and second reflective elements adjacent said first corner; and

at least one imaging device capturing images of said region of interest including reflections from said first and second reflective elements.

[013] In a preferred embodiment, the non-reflective region extends in the planes of both of the first and second reflective elements. The first and second reflective elements may extend only partially along the first and second sides to define a gap at the first corner or may extend fully along the first and second sides and be rendered non-reflective at the first corner.

[014] It is also preferred that the first and second reflective elements extend along sides of a generally rectangular touch surface. In this case, the region of interest includes an active area delineated by a margin extending about the periphery of the touch surface. The margin is sized to inhibit merging of a pointer with one or more pointer reflections in a captured image.

[015] In a preferred embodiment, the apparatus includes a single imaging device looking across the region of interest from a second corner diagonally opposite the first corner. Preferably, the imaging device includes an image sensor with an active pixel sub-array. The first and second reflective elements in this case are configured to aim reflective light towards the pixel sub-array.

[016] According to another aspect of the present invention there is provided an apparatus for detecting a pointer within a region of interest comprising:

a generally rectangular touch surface having an active sub-area defining said region of interest;

a first reflective element extending along a first side of said touch surface and reflecting light towards said region of interest;

a second reflective element extending along a second side of said touch surface and reflecting light towards said region of interest, said second side being joined to said first side at a first corner of said touch surface; and

a detecting device detecting a pointer within said region of interest and reflections of said pointer appearing in said first and second reflective elements and determining the location of said pointer within said region of interest, said active sub-area being sized to inhibit said detecting device from detecting a pointer within said region of interest that merges with one or more of said reflections to an extent that the location of said pointer cannot be resolved.

[017] According to yet another aspect of the present invention there is provided an apparatus for detecting a pointer within a region of interest comprising:

a first reflective element extending along a first side of said region of interest and reflecting light towards said region of interest;

a second reflective element extending along a second side of said region of interest and reflecting light towards said region of interest, said second side being joined to said first side to define a first corner; and

at least one imaging device capturing images of said region of interest and reflections from said first and second reflective elements, said at least one imaging device having an active pixel sub-array and said first and second reflective elements being configured to aim reflected light towards said active pixel sub-array.

[018] According to still yet another aspect of the present invention there is provided an apparatus for detecting a pointer within a region of interest comprising:

a generally rectangular touch surface having an active sub-area defining said region of interest;

a detecting device looking across said sub-area from one corner of said touch surface; and

a first reflective element extending along one side of said touch surface and reflecting light towards said region of interest and towards said detecting device, wherein when a pointer is positioned within said region of interest, said detecting device sees said pointer and a reflection of said pointer appearing in said first reflective element, said active sub-area being sized to inhibit said detecting device from seeing a pointer within said region of interest that merges with said reflection to an extent that said pointer and reflection cannot be resolved.

[019] According to still yet another aspect of the present invention there is provided an apparatus for detecting a pointer within a region of interest comprising:

a first reflective element extending along a first side of said region of interest and reflecting light towards said region of interest;

non-reflective surfaces extending along the other sides of said region of interest; and

at least one imaging device capturing images of said region of interest including reflections from said first reflective element, said at least one imaging device having an active pixel sub-array and said first reflective element being configured to aim reflected light towards said active pixel sub-array.

[020] According to still yet another aspect of the present invention there is provided an apparatus for detecting a pointer within a generally rectangular region of interest comprising:

a detecting device looking across said region of interest from one corner thereof;

a first reflective element extending along one side of said region of interest that is within the field of view of said detecting device and reflecting light towards said region of interest;

non-reflecting surfaces extending along the remaining sides of said region of interest; and

at least one illumination source for providing backlight illumination across said region of interest, wherein when a pointer is positioned within said region of interest, said detecting device sees said pointer directly and a reflection of said pointer in said first reflective surface.

[021] The present invention provides advantages in that the non-reflective region provided near the corner of the region of interest inhibits the imaging device from seeing the true pointer merging with its double reflection. Also, providing the margin about the periphery of the region of interest inhibits the imaging device from seeing the true pointer merge with one or more other pointer reflections. By controlling merging so that the true pointer will not merge with pointer reflections, resolution of the apparatus is maintained.

[022] The present invention provides further advantages in that since the mirrors are configured to aim reflected towards the active pixel sub-array of the imaging device, pointers appearing in the field of view of the imaging device can be detected and their positions relative to the touch surface calculated accurately.

Brief Description of the Drawings

[023] Embodiments of the present invention will now be described more fully with reference to the accompanying drawings in which:

Figure 1 is a schematic view of an apparatus for determining the location of a pointer within a region of interest in accordance with the present invention;

Figure 2 is a plan view of an assembly forming part of the apparatus of Figure 1;

Figure 3 is another plan view of the assembly of Figure 2 showing the region of interest encompassed by the assembly including an active area bounded by margins;

Figure 4 is a side view, partly in section, of a portion of the assembly of Figure 2, showing a mirror assembly;

Figure 5 is a schematic block diagram of an imaging device forming part of the apparatus of Figure 1;

Figure 6 is a plan view showing a pointer within the region of interest and resulting pointer reflections;

Figure 7 is an image captured by the imaging device of Figure 5;

Figures 8a to 8d are plan views showing a pointer within the region of interest at locations resulting in pointer image merging;

Figures 9a to 9d are illustrations showing determination of the margins within the region of interest;

Figure 10 to 13 show captured images, local pointer difference images, horizontal intensity profiles (HIPs) and local pointer binary images;

Figures 14 and 15 are schematic views of alternative embodiments of an apparatus for determining the location of a pointer within a region of interest in accordance with the present invention;

Figures 16 and 17 are schematic views of further alternative embodiments of an apparatus for determining the location of a pointer within a region of interest in accordance with the present invention;

Figures 18 to 20 are alternative mirror assemblies;

Figure 21 is a schematic view of yet a further alternative embodiment of an apparatus for determining the location of a pointer within a region of interest in accordance with the present invention;

Figure 22a is a side view of an alternative embodiment of an illuminated bezel; and

Figure 22b is a top plan view of the illuminated bezel of Figure 22a.

Detailed Description of the Preferred Embodiments

[024] Turning now to Figures 1 to 3, an apparatus for determining the location of a pointer within a region of interest in accordance with the present invention is shown and is generally identified by reference numeral 10. In this particular embodiment, apparatus 10 is in the form of a touch system and is disposed over the display screen of a display unit such as a plasma television, front or rear projection screen or the like (not shown). As can be seen, apparatus 10 includes a generally rectangular assembly 12 encompassing a region of interest ROI and surrounding a transparent touch surface 14 that overlies the display screen. Assembly 12 communicates with a computer 16 executing one or more application programs. The computer 16 uses pointer data generated by the assembly 12 to update computer-generated images that are presented on the display screen. Pointer contacts on the touch surface 14 can therefore be recorded as writing or drawing or used to control execution of application programs executed by the computer 16.

[025] Assembly 12 includes a frame 20 supporting an imaging device 22 adjacent one corner of the touch surface 14. The imaging device 22 has a field of view that looks generally across the plane of the touch surface 14 and is oriented so that its optical axis generally forms a 45 degree angle with adjacent sides of the touch surface 14. A pair of mirrors 24 and 26 is also supported by the frame 20. Each mirror 24, 26 extends along a different side of the touch surface and is oriented so that the plane of its reflecting surface 28, 30 is generally perpendicular to the plane of the touch surface 14. The mirrors 24 and 26 are thus arranged at generally a 90 degree angle with respect to one another and intersect at a corner 32 of the touch surface 14 that is diagonally opposite the imaging device 22. A gap 40 is provided between the two mirrors 24 and 26 at the corner 32 to define a non-reflecting area or region.

[026] The frame 20 also supports infrared illuminated bezels 42 extending along the remaining two sides of the touch surface 14. The infrared illuminated

bezels 42 direct light towards the reflecting surfaces of the mirrors 24 and 26 to provide bands of infrared backlighting for the imaging device 22. A band of infrared illumination directed towards the imaging device 22 is also provided by an illuminated bezel 42 disposed within the gap 40. The imaging device 22 therefore observes a generally continuous band of infrared illumination when no pointer is located within the region of interest. However, when the imaging device 22 acquires an image and a pointer P is located within the region of interest, the pointer P occludes light and appears to the imaging device 22 as a black or dark object against a white background. The infrared illuminated bezels 42 are the same as those described in U.S. Patent Application No. 10/354,168 entitled "Illuminated Bezel And Touch System Incorporating The Same" to Akitt et al. filed on January 30, 2003 and assigned to SMART Technologies Inc, assignee of the present invention, the content of which is incorporated herein by reference. Accordingly, specifics of the infrared illuminated bezels 42 will not be described further herein.

[027] The region of interest ROI is bounded by bottom, top, left and right margins M_{bot}, M_{top}, M_{left}, M_{right} respectively to define an active area 34. The height of the region of interest is determined by the geometry of the mirrors 24 and 26, the illuminated bezels 42 and the field of view of the imaging device 22. In the present embodiment, each of the margins has a one-inch width giving the active area 34 a diagonal dimension equal to 72 inches. The size of the gap 40 is a function of the size of the touch surface 14, the widths of the margins and the size of the pointer used to contact the touch surface 14. Further specifics concerning the manner by which the gap and margin sizes are calculated will be described herein.

[028] Each mirror 24, 26 is supported on the frame 20 by a right angle extruded bracket 50 as shown in Figure 4. Each bracket 50 is secured to the frame 20 by fasteners 52 in the form of blind rivets that pass through the leg 50a of the bracket 50 that overlies the frame 20. Adhesive 54 is placed between the leg

50a and the frame 20 to secure further the bracket 50 to the frame and inhibit the bracket from moving relative to the frame even if the rivets 52 loosen. The adhesive 54 also acts as a filler. The mirror is secured to other leg 50b of the bracket 50 by adhesive 56 to inhibit relative movement between the bracket 50 and the mirror. In the preferred embodiment, GE Silicone SE1124 All Purpose Silicone Seal is used as the adhesive.

[029] The reflective surfaces 28 and 30 of the mirrors 24 and 26 are generally planar and are oriented so that the bands of backlight illumination provided by the illuminated bezels 42, when reflected by the mirrors, are directed towards an active pixel sub-array of the imaging device 22. Orienting the mirrors 24 and 26 so that the reflective surfaces achieve this desired function maintains the resolution of the apparatus 10 allowing pointer hover and pointer contact with the touch surface 14 to be accurately determined. To align the mirrors, during assembly, adhesive 56 is placed along the leg 50b of each bracket 50 and the mirrors are set in place. While the adhesive 56 is setting, the tilt of each mirror is adjusted until the backlighting reflected by the reflective surface is directed toward the active pixel sub-array of the imaging device 22. Once the adhesive 56 sets, the mirrors 24 and 26 are securely held by the adhesive 56 thereby to maintain their orientation.

[030] The imaging device 22 is best seen in Figure 5 and includes a high resolution 1280x1024 CMOS digital camera 60 such as that manufactured by National Semiconductor under model No. LM9638 and an associated lens 62. A digital signal processor (DSP) 64 is coupled to the digital camera 60. The digital camera 60 and DSP 64 are mounted on a common circuit board. The circuit board is positioned with respect to the touch surface 14 so that the digital camera 60 looks out across the plane of the touch surface 14. The lens 62 has a 98 degree field of view so that the entire active area 34 is within the field of view of the digital camera 60 plus 4 degrees of tolerance on either side of the region of interest. The DSP 64 is also coupled to the computer 16 via a universal serial bus

(USB) or RS232 serial cable 66. The digital camera 60 preferably is configured to have a 1280x40 active pixel sub-array allowing it to be operated to capture image frames at high frame rates (i.e. in excess of 200 frames per second).

[031] During use, when a pointer P is brought into the active area 34 of the region of interest ROI and therefore, into the field of view of the digital camera 60, the pointer P occludes the backlight illumination emitted by the illuminated bezel 42 in the gap 40 and the backlight illumination reflected by the mirrors 24 and 26. When the digital camera 60 captures an image and a pointer P is in the image, depending on the position of the pointer P, the captured image includes dark areas representing the pointer P and images or reflections of the pointer. Depending on the location of the pointer relative to the active area 34 different scenarios may occur. For example, the captured image may include dark areas representing the true pointer P_T, and three images of the pointer resulting from right, left and double pointer reflections P_R, P_L, P_D respectively or may include dark areas representing the true pointer P_T, and two pointer images. Figure 6 shows the true pointer P_T and the pointer reflections P_R, P_L, P_D as seen by the digital camera 60 as a result of occluded backlighting and the angles $Ø_0$ to $Ø_3$ associated with the true pointer P_T and the pointer reflections P_R, P_L, P_D. Figure 7 shows a captured image including the true pointer P_T and the pointer reflections P_R, P_L and P_D.

[032] Although the touch system 10 includes only a single digital camera 60, the use of the mirrors 24 and 26 to reflect images of the pointer P towards the digital camera 60 effectively creates a touch system that is four times as large with virtual cameras at each of its corners as shown in Figure 6. In this case, the pointer reflections can be considered to be seen by virtual cameras with the pointer reflections in the mirrors 24 and 26 determining the positions of the virtual cameras. Angles are associated with the virtual camera images and these angles are identical to the angles $Ø_0$ to $Ø_3$ associated with the true pointer and pointer reflections.

[033] In order to determine the position of the pointer P relative to the touch surface 14, it is necessary to distinguish between the true pointer and the various pointer reflections in the captured image. Relying on the geometry of the touch system 10, the following relationships between the angles $\varnothing_1$ to $\varnothing_3$ hold true. $\varnothing_2$ is less than or equal to $\varnothing_1$, which is less than or equal to $\varnothing_0$. $\varnothing_2$ is less than or equal to $\varnothing_3$, which is less than or equal to $\varnothing_0$. As a result, the outer two pointers in the captured image always correspond to angles $\varnothing_2$ and $\varnothing_0$ and the two inner pointers in the captured image always correspond to angles $\varnothing_1$ and $\varnothing_3$.

[034] When the captured image includes four dark areas representing the true pointer P_T, the right pointer reflection P_R, the left pointer reflection P_L and the double pointer reflection P_D, distinguishing between the true pointer and the pointer reflections is a straightforward process. The dark area to the extreme left is the left pointer reflection P_L and the dark area to the extreme right is the right pointer reflection P_R. To distinguish between the true pointer P_T and the double pointer reflection P_D, i.e. the two intermediate dark areas, the column of the active pixel sub-array that contains the diagonal vertex, i.e. the midpoint of the illuminated bezel 42 within the gap 40, is determined. Once the column location of the diagonal vertex is determined, the columns of the active pixel sub-array that contain the two intermediate dark areas are determined. The distances between the columns that contain the two intermediate dark areas and the column containing the diagonal vertex are compared. Since the double pointer reflection P_D is always further away from the imaging device 22, the column separation between the double pointer reflection P_D and the diagonal vertex is always smaller than the column separation between the true pointer P_T and the diagonal vertex. As a result by comparing the column separation between the intermediate dark areas and the diagonal vertex, the true pointer P_T can be easily distinguished from the double pointer reflection P_D.

[035] When the captured image includes three dark areas, the column location of the diagonal vertex is again determined and the number of dark areas

on each side of the diagonal vertex area are determined. If two dark areas are to the left of the diagonal vertex and one dark area is to the right of the diagonal vertex, two scenarios are possible. In one scenario, the true pointer P_T is merging with the right pointer reflection P_R. In this case, the left dark area is the left pointer reflection P_L and the middle dark area is the double pointer reflection P_D. The right dark area includes both the true pointer P_T and the right pointer reflection P_R. The other scenario is that the double pointer reflection P_D is missing as a result of the non-reflective region associated with the gap 40. To determine which scenario exists, again the pointer data is processed for both scenarios and the scenario that yields a correctly triangulated location is determined to be correct. If both scenarios yield a correctly triangulated location, the position of the middle dark area relative to the diagonal vertex is determined. If the double pointer reflection P_D is missing, the true pointer P_T will be very close to the diagonal vertex.

[036] Similarly if two dark areas are to the right of the diagonal vertex and one dark area is to the left of the diagonal vertex, two scenarios are possible. In one scenario, the true pointer P_T is merging with the left pointer reflection P_L. In this case, the right dark area is the right pointer reflection P_R and the middle dark area is the double pointer reflection P_D. The left dark area includes both the true pointer P_T and the left pointer reflection P_L. The other scenario is that the double pointer reflection P_D is missing as a result of the non-reflective region associated with the gap 40. To determine which scenario exists, again the pointer data is processed for both scenarios and the scenario that yields a correctly triangulated location is determined to be correct. If both scenarios yield a correctly triangulated location, the position of the middle dark area relative to the diagonal vertex is determined. If the double pointer reflection P_D is missing, the true pointer P_T will be very close to the diagonal vertex.

[037] Knowing the true pointer P_T and two or more of the pointer reflections P_R, P_L and P_D as well as the angles $\varnothing_0$ to $\varnothing_3$, the pointer position relative to the touch surface is calculated using triangulation as described in U.S.

Patent Application No. 10/294,917 filed on November 15, 2002 for an invention entitled “Size/Scale And Orientation Determination Of A Pointer In A Camera-Based Touch System” to Morrison et al, assigned to SMART Technologies Inc., assignee of the present invention, the content of which is incorporated herein by reference. Thus, a bounding area representing the pointer location relative to the touch surface 14 is determined and conveyed to the computer 16.

[038] The margins are provided about the periphery of the active area 34 to avoid pointer identification ambiguity that may occur if the pointer P gets too close to the mirrors 24 and 26, too close to the imaging device 22 or too close to the diagonal vertex, i.e. corner 32. When the pointer P gets too close to the mirror 24 adjacent the illuminated bezel 42, the true pointer P_T and left pointer reflection P_L will merge and the right pointer reflection P_R and double pointer reflection P_D will merge as shown in Figure 8a. When the pointer P gets too close to the mirror 26 adjacent the illuminated bezel 42, the true pointer P_T and right pointer reflection P_R will merge and the left pointer reflection P_L and double pointer reflection P_D will merge as shown in Figure 8b. When the pointer P gets to close to the imaging device 22 or too close to the diagonal vertex, the true pointer P_T and the left, right and double pointer reflections will merge as shown in Figures 8c and 8d. Assuming that the active area 34 has a diagonal dimension equal to 72 inches with a 4:3 aspect ratio where the pointer can go right to the extreme edges of the active area 34 and, assuming a maximum pointer diameter equal to ¾ inch, the dimensions of the margins are determined as follows.

[039] The widths of the margins M_{bot} and M_{right} are determined by the situation where the pointer P gets too close to the imaging device 22 and are calculated as follows with reference to Figure 9a.

[040] When θ_2 is less than θ_1, the true pointer P_T and the left pointer reflection P_L will merge. Thus, in order to prevent merging, θ_2 must be larger than θ_1. To calculate margin M_{bot}, the smallest M_{bot} is desired while ensuring θ_2 is bigger than θ_1.

[041] The calculation of margin M_{bot} depends on the values chosen for margins M_{left} and M_{right}. In order to simplify the calculations, assume margins M_{left} and M_{right} both have widths equal to one inch. Using standard trigonometry, it can be deduced that:

$$\tan(\theta_1) \cong (M_{bot} + (\text{pointer diameter}/2)) / (2 \times 4 \times 72/5 + M_{right} + 2 \times M_{left})$$
$$\theta_1 \cong \arctan ((M_{bot} + 0.375) / 118.2) < 1°$$

Substituting the measurements given above for the apparatus 10, it can be seen that $\theta_1 < 1°$. Similarly, it can be shown that:

$$\theta_2 \cong 90° - \arctan(M_{right} / M_{bot}) - \arcsin ((\text{pointer diameter}/2) / \text{sqrt}((M_{right})^2 + (M_{bot})^2))$$

[042] While it is possible to solve for margin M_{bot} using analytic techniques, it is also possible to use a trial and error technique. The trial and error technique involves selecting a potential value for margin M_{bot} and computing θ_2 using the above equation. If θ_2 is larger than θ_1, then the selected margin M_{bot} is acceptable and will inhibit pointer merging. By way of example, if margin M_{bot} has a width equal to ½ inch and margin M_{right} has a width equal to 1 inch, θ_2 is 7°, which is larger than θ_1.

[043] A similar technique can be applied to margin M_{right} and a value can be computed for a given margin M_{bot}. Consider the example shown in Figure 9b, with margin M_{bot} and M_{right} both having widths equal to ½ inch. In this case, θ_1 for the bottom edge is 0.45 degrees and θ_1 for the right edge is 0.6 degrees. θ_2 for both cases works out to approximately 30 degrees, which clearly satisfies the condition that $\theta_2 > \theta_1$ along both edges.

[044] In order to inhibit pointer merging when the pointer P is too close to the mirrors near the illuminated bezels or too close to the diagonal vertex, a margin is introduced along the left and top sides of the active area 34. The worst case

generally happens at the corner 32 diagonally opposite the imaging device 22 if the mirrors intersect at that corner. As will be appreciated, if the mirrors 24 and 26 extended along the entire lengths of the touch surface sides and intersected at the corner 32, when a pointer P is positioned near the corner 32, in a captured image the true pointer P_T and the double pointer reflection P_D will merge as shown in Figure 9c. In this case, resolution decreases since the area of the bounding area representing the pointer location relative to the touch surface 14 increases. The gap 40 between the mirrors 24 and 26 at the corner 32 is provided to eliminate the double pointer reflection P_D when the pointer P is near the corner 32. Specifically, for a given pointer size and a given touch surface size, the gap 40 is selected so that at no point on the touch surface will the true pointer P_T merge with the double pointer reflection P_D.

[045] Using the same dimensions as above, the angles that bound the true pointer P_T are 36.65° and 37.25° as shown in Figure 9d. Using trigonometric techniques, it can be shown that:

$M_{left} \geq$ pointer radius / sin(36.65°) $\geq$ 0.63"

$M_{top} \geq$ pointer radius / cos(37.25°) $\geq$ 0.47"

[046] In practice, the separation between the true pointer and a pointer reflection should be large enough such that the imaging device 22 can resolve the difference between the true pointer and the pointer reflection. Generally, the widths of the margins are selected to be greater than the minimum widths to take into account limitations in the resolving power of the imaging device 22 as well as the fact that the pointer P may be held at an angle relative to the touch surface.

[047] When a pointer is positioned adjacent a corner of the touch surface 14 where one of the illuminated bezels 42 and mirrors meet, the true pointer and the pointer reflection from the nearest mirror merge. In this case, whenever a pointer image includes two pointer tips, the actual locations of the true pointer P_T

and the pointer reflection are ascertained using the shape of the bounding box surrounding the merged images.

[048] The optical axis of the digital camera 60 is also at an oblique angle with respect to the plane of the touch surface 14 so that when a pointer P is in the active area 34 of the region of interest, the digital camera 60 sees the true pointer and the pointer reflections as well as reflections of the true pointer and the pointer reflections off of the touch surface 14. Pointer contacts with the touch surface 14 are determined when the true pointer and pointer reflections and their reflections off of the touch surface are in contact. Pointer hover is determined when the true pointer and pointer reflections and their reflections off of the touch surface 14 are spaced apart. Further specifics of this contact detect determination are described in U.S. Patent Application No. 10/384,796 filed on March 11, 2003 for an invention entitled "Touch System And Method For Determining Pointer Contacts On A Touch Surface" to Morrison et al, assigned to SMART Technologies Inc., assignee of the present invention, the content of which is incorporated herein by reference.

[049] Due to optical and mechanical limitations, in some instances even when a pointer is hovering over the touch surface 14, one or more of the true pointer and pointer reflections may appear to be in contact with their reflections off of the touch surface 14. To enhance contact detect, difference images are generated by subtracting current images of the true pointer and pointer reflections from the corresponding locations in a background image captured upon initialization of the apparatus. Then, a horizontal intensity profile (HIP) of the true pointer's and pointer reflection's difference image is combined with the captured binary image.

[050] Figure 10 shows a captured image including a true pointer and pointer reflections, four local difference images Dfn1 to Dfn4, the HIPs of the true pointer and pointer reflections together with associated threshold lines and processed binary images. The threshold line for the true pointer and pointer reflections is obtained by taking the average intensity value of the background plus

two times the standard deviation. When a pointer P is in contact with the touch surface 14, each HIP should be above its threshold line and each binary image of the pointer should be solid as shown in Figure 10. When a pointer P is hovering above the touch surface 14, each HIP should extend below its threshold line and each binary image of the pointer should show a gap as illustrated in Figure 11.

[051] In some instances, an HIP and associated binary image may be inconsistent. For example, in Figure 12, the HIP associated with the fourth pointer dark area extends below its threshold line yet the binary pointer image is solid. Situations where an HIP is above its threshold yet the associated binary pointer image shows a gap can also occur. As a result, determining contact using only HIPs or binary images can yield inaccuracies. Accordingly, when any of the following two conditions are met, the pointer P is determined to be hovering over the touch surface 14; otherwise it is determined to be in contact with the touch surface:

for at least two pointers, there is a gap of the pointer in the binary image; or

for at least one pointer, the associated HIP extends below its threshold line and there is a gap of the pointer in the binary image and for at least two pointers their associated HIPs extend below their threshold lines.

[052] It is possible that pointers may satisfy both conditions as illustrated in Figure 13. As can be seen the pointer is hovering above the touch surface and both of the above conditions are satisfied. Alternately contact states may be determined by examining the true pointer only.

[053] Turning now to Figures 14 and 15, an alternative embodiment of an apparatus in accordance with the present invention is shown and is generally identified by reference numeral 210. In this embodiment, the illuminated bezels are replaced with non-reflective material 242 and an active pointer P' is used to contact the touch surface 214. The active pointer includes a tip switch (not shown) and a light source 215 adjacent the tip of the active pointer. The light source 215

is preferably an infrared light emitting diode (IR LED). When the tip of the active pointer P' is brought into contact with the touch surface 214, the tip switch is activated and the IR LED is illuminated.

[054] When the pointer P' is in contact with the touch surface 214 and the pointer emits infrared light, light rays are emitted by the IR LED as shown in Figure 15. In this case, light ray LR_1 travels directly to the imaging device 222. Light rays LR_2 and LR_3 reflect off of one of the mirrors before travelling to the imaging device 222. Light ray LR_4 reflects off of both mirrors before travelling to the imaging device 222. As a result, the imaging device 222 sees either three or four pointer images allowing the position of the pointer P' relative to the touch surface 214 to be determined in the manner described previously. If desired, the active pointer P' may include two LEDs of different frequencies. In this case, one of the LEDs is illuminated when the pointer P' is out of contact with the touch surface 214 and is used to indicate hover. When the pointer P' is brought into contact with the touch surface 214, the tip switch activates the other LED and deactivates the hover LED. As a result, light of one frequency received by the imaging device 222 represents a hover condition while light of a different frequency received by the imaging device 222 represents a contact condition. Illuminated bezels 42 may be provided along the sides of the touch surface 214 with the illuminated bezels being turned off when an active pointer P' is being used and turned on when a passive pointer is being used. This of course yields an apparatus with dual passive/active pointer functionality.

[055] Turning now to Figures 16 and 17, yet another embodiment of an apparatus suitable for use with a passive pointer in accordance with the present invention is shown and is generally identified by reference numeral 310. In this embodiment, the illuminated bezels are replaced with retro-reflectors 342. Infrared LEDs 323 are positioned adjacent the imaging device 322 and direct infrared light into the region of interest. Light emitted by the infrared LEDs 323 travels across the touch surface 314, reflects off of one or both mirrors and strikes a retro-

reflector 342. The retro-reflector 342 in turn reflects the light back in the direction from which it came and thus, the reflected light is returned to the imaging device 322. As a result, when no pointer is within the field of view of the imaging device, the imaging device 322 sees a brightly-lit band. However, when a pointer P" is brought into the region of interest, the pointer occludes light and thus, the pointer and its reflections appear in captured images as dark areas. As a result, the imaging device 322 sees either three or four pointer images allowing the position of the pointer relative to the touch surface 314 to be determined in the manner described previously. Rather than using retroreflectors 342, high contrast material such as a black matte paint or felt can be provided along the sides of the touch surface.

[056] Although the apparatuses have been described as including generally planar mirrors that are affixed to brackets by adhesive to maintain their desired orientations, other designs to reflect backlight illumination towards the active pixel sub-array of the imaging device are of course possible. For example, if desired, each mirror 401 may be connected to one side of the frame 402 via a pair of piano-type hinges 400 as shown in Figure 18. A mirror adjustment mechanism 402 acts between the frame and the mirror and is generally centrally mounted on the side of the frame between the hinges 400. The mirror adjustment mechanism includes a mounting fixture 404 secured to the frame by suitable fasteners 406 such as, for example, blind rivets. A retaining post 408 extends upwardly from the top of the mounting fixture 404. A fine pitch screw 410 engages a threaded hole provided through the mounting fixture 404 and can be rotated to alter the distance by which the distal end of the screw 410 extends beyond the mounting fixture 404 towards the mirror. A bracket 412 engages the top of the mirror at a location in line with the screw 410. A second retaining post 414 extends upwardly from the top of the bracket 412. A biasing element 416 in the form of a loop of elastic cord engages the retaining posts 408 and 414 to bias the mirror so that the bracket remains in contact with the screw 410. Alternatively, the biasing element may take

the form of a spring or other resilient element that urges the mirror toward the mounting fixture 404. During mirror alignment, the screw 410 is rotated in the appropriate direction either to tilt the mirror towards or away from the imaging device until the backlighting reflected by the mirror is directed towards the active pixel sub-array. The biasing element 416 acting between the bracket 412 and the mounting fixture 404 inhibits the mirror from moving once the mirror is in the desired orientation.

[057] In a further embodiment, rather than using planar mirrors, curved mirrors can be used. In this case, the reflective surfaces of the mirrors are generally convex so that the bands of backlight illumination provided by the illuminated bezels when reflected by the mirrors are directed towards the active pixel sub-array of the imaging device. Curving the mirrors increases the fields of view of the mirrors and hence, reduces mounting tolerances. In this embodiment, the mirrors have a radius of curvature equal to approximately 100 inches. The radius of curvature of the mirrors and the height of the infrared illuminated bezels are selected so that at least ½ inch of the pointer tip is illuminated by reflected infrared backlighting when the pointer is in the region of interest and in contact with the touch surface.

[058] In yet another embodiment, the mirrors may include a pair of reflective surfaces 502 and 504 arranged 90 degrees with respect to one another to form a V-configuration as shown in Figure 19. As can be seen, each mirror is formed from a pair of stacked trapezoidal metal pieces 506 and 508, in this case aluminum, each having a polished highly reflective surface. The metal pieces carry mating formations such as locating pins 510 and complimentary holes to position accurately the metal pieces relative to one another and to locate the mirrors on the frame.

[059] In still yet another embodiment, the mirrors may include corrugated reflective surfaces 602 defined by stacked pairs of reflective surfaces arranged 90 degrees with respect to one another as shown schematically in Figure 20. In this

case, each mirror is formed of a block of acrylic material having one surface that is compression molded to define a corrugated surface including a series of stacked V-grooves such as that manufactured by Fresnel Optics under model number PR713. A reflective coating is applied to the corrugated surface by sputtering or other suitable technique. The mirror is positioned on the frame with the corrugated reflective surface nearest the imaging device. Alternatively, the mirror may be positioned on the frame with the corrugated reflective surface furthest from the imaging device. In this case, the backlight illumination enters and travels through the block of material before being reflected back by the corrugated reflective surface.

[060] Although the gap has been shown and described as extending along two sides of the region of interest, those of skill in the art will appreciate that the non-reflective region associated with the gap need only extend along one side of the region of interest to inhibit the double pointer reflection from occurring when the pointer is adjacent the corner 32. Also, although the non-reflective region is shown as a gap between the mirrors 24 and 26, if the mirrors join at the corner 32, the mirrors can be rendered non-reflective at the corner 32 using a suitable coating or covering to define the non-reflective region.

[061] Turning now to Figure 21, yet another embodiment of an apparatus in accordance with the present invention is shown and is identified by reference numeral 710. In this embodiment, only a single mirror 724 is provided along one side of the region of interest. The remaining sides are coated with a high contrast material 742, in this case a black matte paint or felt. Similar to the embodiment of Figures 16 and 17, infrared LEDs (not shown) are positioned adjacent the imaging device 722 and direct infrared light into the region of interest. Since only one mirror is utilized in this embodiment, fewer images of the pointer appear in captured images although sufficient pointer images appear in order to triangulate the position of the pointer. Also, since only one mirror is utilized, an L-shaped

margin extending along two sides of the active area 734 is required to inhibit pointer image merging.

[062] Figures 22a and 22b show an alternative design for the illuminated bezels generally at 800. As can be seen, in this embodiment the illuminated bezel 800 includes a parabolic collimator 804 formed on an internal bezel surface that reflects light from an LED 808 back across the touch surface 814 on paths parallel to the touch surface 814. A lenticular array 820 positioned between the touch surface 814 and the collimator 804 and LED 808 disperses the light reflected by the collimator 804 across the touch surface 814. The lenticular array 820 can, for example, have a number of facets that redirect light within a horizontal plane above the touch surface 814, while preserving its vertical component to ensure that the light travels across the touch surface 814 and not away from or towards it. By redirecting a significant portion of the light from the LED 808 across the touch surface 814, a greater intensity of light is viewed by the imaging device, thus providing better resolution in the images captured. As seen in Figure 22b, by positioning the LED 808 a significant distance from the collimator 804, light is dispersed over a broad area by the lenticular array 820. In this manner, the touch surface is illuminated relatively evenly using a limited number of light sources. The collimator and lenticular array may be combined into a dual-sided thin film placed in between the LED and the region of interest.

[063] The digital camera is described as being mounted on a circuit board and positioned so that its field of view looks across the plane of the touch surface. As will be appreciated, the circuit board can of course be located at different locations. In this case, folding optics are used to aim the field of view across the plane of the touch surface. As will also be appreciated a variety of different types of imaging devices can be used to capture images such as for example CCD sensors and line arrays.

[064] Although preferred embodiments of the present invention have been described, those of skill in the art will appreciate that variations and modifications

may be made without departing from the spirit and scope thereof as defined by the appended claims.